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STUDY OF THE NATIONAL SCIENCE FOUNDATION'S SOUTH POLE STATION AS AN ANALOGOUS DATA BASE FOR THE LOGISTICAL SUPPORT OF A MOON LABORATORY

(Center Director's Discretionary Fund Final Report No. 307-51-00-N09)

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Science and Engineering Directorate

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The day will come when the United States will want to return to the Earth's Moon. When that occurs, NASA may look to the Apollo program for technical and inspirational guidance. The Apollo program, however, was designed to be an end to itself—the landing of a man on the Moon and his return safely within the decade of the 1960's. When that was accomplished, the program folded because it was not self-sustaining. The next time we return to the Moon, we should base our planning on a program that is designed to be a sustained effort for an indefinite period. It is the thrust of this report that the South Pole Station of the National Science Foundation can be used to develop analogs for the construction, funding, and logistical support of a lunar base. Other analogs include transportation and national efforts versus international cooperation. A recommended lunar base using the South Pole Station as inspiration is provided, as well as details concerning economical construction of the base over a 22-year period.

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TECHNICAL MEMORANDUM

STUDY OF THE NATIONAL SCIENCE FOUNDATION'S SOUTH POLE STATION AS AN ANALOGOUS DATA BASE FOR THE LOGISTICAL SUPPORT OF A MOON LABORATORY

I. INTRODUCTION

The day will come when the United States will want to return to the Earth's Moon. That requirement will be based on one of the following perceived needs:

- Science
- International cooperation
- Energy development (helium 3, solar collectors)
- Geologic development (titanium, other)
- Exploration
- Nationalistic impetus (another space race?)
- Off-Earth pilot habitats (to learn how to live off-Earth)
- Groupings of the above.

When one of these perceived needs becomes great enough, the United States and NASA will look to the Apollo program for technical and inspirational guidance. But Apollo was designed to be an end to itself—the landing of a man on the Moon and his return safely within the decade of the 1960's. When that was accomplished, the program folded because it was not self-sustaining. The next time we return to the Moon, the true inspiration we should look for is something very similar to our operations in the Antarctic as an applicable historical analog.

The fact that there is no compelling reason to return to the Moon today is no assurance that such will not be the case very quickly tomorrow. In fact, for those who study the historical cycles of exploration and science, there is a sense of inevitability that, regardless of the costs or the politics or other extenuating circumstances, eventually the country that has dominated this century in science and industry will wish to explore and build space-based communities. One basic concept to begin this effort is an economical return to the Moon for the purpose of utilizing it scientifically and developing it commercially. This return will be driven primarily by the relatively easy access of the Moon (as compared to Mars and other planets of the solar system) and the gradual recognition that it is a resource that the Earth cannot and should not ignore forever. The return may be in the form of an international expedition, but probably the emphasis from the United States will be on two parallel tracks that will eventually merge—science and industrial development.

In order to learn the most about the Moon and exploit its unique environment, scientists and engineers will have to spend weeks, even months, on the lunar surface. To accomplish that, an outpost will have to be established. But what kind of outpost? To gain insight on the likely scenario of a lunar outpost, the history of the exploration of the Antarctic continent and specifically the attempts to reach the geographical South Pole may serve as a harbinger of the future.

The first expeditions to the South Pole in the late 19th and early 20th century were essentially sprints and publicity stunts, primarily accomplished for national prestige and personal glory, although often wrapped in the dubious veneer of science. These sprints were accomplished with the technology of the day—steamships to the ice shelf followed by the use of dogs and manpower to make a torturous journey to the pole and return. Many men died and many more suffered from frostbite, hunger, and exhaustion. Roald Amundsen, a Norwegian, reached the Pole first on December 14, 1911, followed quickly by his competitor, Englishman Robert Scott (who died with his entire team on the trip back). After these highly adventurous and publicity-conscious "firsts" had been accomplished, however, interest waned in duplicating the feats. It was far too expensive in money and human life to do something that had already been done. The South Pole as a destination was abandoned. These sprints might be seen as roughly equivalent to our Apollo Program which was based as much on Cold War politics as it was on science or even exploration. Just as the initial conquering of the South Pole, the Moon was abandoned as too expensive for the likely gain. Nevertheless, we are back at the South Pole and, similarly, we will return to the Moon and probably because of the same reason: new technology will make it much easier.

Four decades after the initial nationalistic South Pole sprints, technology had changed sufficiently that the South Pole became a goal once more. Rather than a desperate expedition, the next group to arrive at the South Pole were Americans who simply flew there in an airplane. They landed on October 31, 1956, and construction of a South Pole station began a month later. The chronology of the attainment of the South Pole, sprints pushing the available technology to the limit, followed by a long respite, and then a return using advanced technology and the construction of a permanent base, might be the chronology that lunar development will also follow.

It is the thrust of this report that the South Pole Station of the National Science Foundation (NSF) can be used to develop an analog for the construction, funding, and logistical support of a Moon base.

II. THE NATIONAL SCIENCE FOUNDATION'S AMUNDSEN-SCOTT SOUTH POLE STATION AS LUNAR BASE ANALOG

Clearly, the NSF's South Pole Station at least looks like a lunar science station might look. The central area of the station is located beneath an aluminum geodesic dome. The dome houses three two-story structures which contain living, dining, communications, recreation, laboratory facilities, and conference rooms. The station can accommodate a crew of 24 during the winter period (when the station is completely cut off from the outside), and a crew of up to 40 during the summer, with another 60 people in the emergency facility called Summer Camp. A series of steel arches run perpendicular to the axis of the dome's main entryway and houses a garage complex, gymnasium, carpentry shop, power plant, biomedical facility, and main fuel storage. The fuel arch contains nine 25,000-gal bladders, giving the station a maximum capacity of 950,000 L or 225,000 gal of diesel fuel, arctic DF-A. The four-story skylab and the balloon inflation tower adjoin the main station and are accessible through covered archways. The clear air facility for atmospheric chemistry lies 100-m upwind of the station. Other research modules are located at various distances from the station.

Primary station power is provided by one of three 350-kW generators. Waste heat is utilized for station heating via a glycol circulation system that conducts the heated coolant through the various station structures. Another glycol loop supplies heat to the snow melter for the station's water supply. These systems, as well as water, sewage, phone, computer, and electric lines, are routed through a series of underground steel utility corridors, termed utilidors. The South Pole Station is supported and managed by a contractor. The United States Navy and Air Force supplies transportation and other logistical needs. All support groups work under contract to the NSF.

By this description, it is clear that the South Pole Station satisfies most of the criteria of the lunar base analog. It is remote, difficult to get to, requires external resupply, and must be self-sufficient during long periods for power and personnel support.

III. THE EVOLVING CONSTRUCTION ANALOG

The Amundsen-Scott Antarctic base (South Pole Station) was constructed in stages, each summer season allowing more construction and more capability to be added to the base. At first, the base was only available for short visits. Gradually, enough infrastructure was built to allow wintering-over and permanent habitation. Initial design and construction of the station did not guarantee this would occur but it did allow iterative growth. If it was seen to be valuable, additional capacity was allowed. Gradually, the present capability was attained, not as a great and expensive goal, but simply as evolutionary. The construction of a lunar station should be similar. This might avoid great debates as to cost and function. Initial goals should be small. A step-by-step approach will give us a lunar base without the pain of the inevitable reassessments huge programs and complex goals attract. A plan for the evolutionary construction of a lunar station using as much as possible already paid-for designs is presented in appendix A.

IV. THE FUNDING ANALOG

Just as construction, funding for a lunar base can use the South Pole Station analog. Funding should be spread over a period of time and should be a level requirement each fiscal year. A lunar base could very well mean a tremendous boost to the American economy, adding much more than it takes, but it should not be sold as such since it is by no means guaranteed. The lunar station should be an economical one, logically spread out over a period of time, using as much of the existing space transportation infrastructure as possible. A funding plan for the lunar base is presented in appendix B.

V. THE TRANSPORTATION ANALOG

The NSF used available transportation to transport construction materials, supplies, and personnel to build its Antarctic base. The United States Navy and the Air Force, for the most part, are the agencies that supply that transportation. There is, however, no similar agency that has the transportation required to carry the construction materials, supplies, and personnel to the Moon. The entity that builds the lunar base, then, must supply its own transportation to the Moon, or some other entity has to be created to provide that transportation. It is suggested that a government-regulated utility is the best method to create this transportation system. When estimating the costs of the lunar base, transportation is by far the major factor. The lunar transit utility (LTU) will be charged to keep those costs to a minimum and definitely not to exceed the annual budget. The proposed organization of the LTU along with the space transportation systems and manifest required is shown in appendix C. Although it is presented as a way to get to the Moon based on present technology, it should be recognized that this is the weakest of the links in Moon base development. A transportation revolution would be very helpful.

VI. THE LOGISTICS ANALOG

The use of a logistical data base from the NSF South Pole Station would be very helpful in determining the resupply requirements for a lunar base. That was the first goal of the principal investigators of this Center Director's Discretionary Fund (CDDF) project. Several teleconferences were conducted with NSF personnel to develop the requirements. Also, much research was done in logistical manuals already in existence such as the United States Army's Engineer Field Data (FM 5-34). The use of the data found in that manual and applied to a lunar station is presented in appendix D. When it was clear that the NSF and the United States Navy had not kept records on either the construction materials used for the South Pole Station, or records on materiel logistics, or sociological data in a systematic way, it was evident that two phases of research would be required. The first phase would be to interview NSF and navy personnel and gather information through a questionnaire. The second phase would then be to conduct further research using whatever raw data existed. Accordingly, a questionnaire for the NSF was developed and is included in appendix E. After investigation, it was discovered that raw data were available on the station, located in the National Archives. National Archives researchers were contacted, and a list of South Pole Station data was obtained. This is included in appendix F.

VII. THE NATIONAL PROGRAM AND INTERNATIONAL COOPERATION ANALOG

The Antarctic analog is also interesting to study in terms of international cooperation as well as nationalistic tendencies. The recent history of the exploration and scientific investigation of the Antarctic continent shows that there are many examples of both international cooperation as well as nationalistic displays. At present, all the stations in Anarctica are constructed and maintained by individual nations who have, in effect, carved out areas of dominance. Argentina, for example, has even made some territorial claims, going so far as to bring immigrants to their sites for home-steading. Such a mix, based on treaty and nationalistic needs, might also be expected on the Moon. Based on this analog, it should not be expected that international lunar bases will be the rule.

VIII. THE SPACE EXPLORATION INITIATIVE AND ITS DEMISE

While this CDDF initiative was beginning to gain focus and momentum, another NASA program was also beginning to form. This was President Bush's Space Exploration Initiative (SEI). One of the methodologies of that effort was to utilize Earth-based resources to determine the requirements for lunar and Mars bases. It was inevitable that SEI would eventually want to look at the NSF's South Pole Station. That was exactly what occurred in early 1991. Johnson Space Center was given primary responsibility to conduct research with the NSF on the use of Antarctic bases as analogs for future NASA bases. At that time, NSF personnel no longer were allowed to work with the principle investigators of this CDDF initiative. Since that time, however, SEI has been canceled. Nevertheless, NASA headquarters continues an effort, and this report will be forwarded there to offer the information gained in our study.

IX. SUMMARY

The planning accomplished and set forth in this report reflects the use of the South Pole Station as an analog for a lunar base. Using the success of the South Pole Station as a foundation, any designer of a lunar station can proceed in confidence. It is also very clear that the NSF and NASA should work closely on any lunar base to provide it with the important knowledge and experience each agency holds.

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APPENDIX A

THE EVOLVING CONSTRUCTION ANALOG

Much of NASA's past history has led the agency in the direction of a "single launch" strategy whereby everything required for a mission was sent into space on a single carrier and essentially ready to be operated. Examples include Apollo, *Skylab*, and Spacelab. The primary reason for this is obvious: the hardest and most expensive part of the job is boosting the hardware into space so a single launch is attractive from a pure cost standpoint. Construction in space is also an unknown. Depending on the requirements, it can be expected that construction in space will be potentially difficult, expensive, unsafe, and unsuccessful. Nevertheless, the complex nature of a lunar base will probably require that it be built in stages. But what will those stages be? The historical analog of the construction of the South Pole Station is applicable. The lunar base will have many components but it can become operational with just a few of them at the beginning (some small habitats, fuel cells or solar power, etc.). Additional construction over many years can then create the fully functioning base.

It is the proposal of this report that our first lunar base be built using Space Station *Freedom* (S.S. *Freedom*) designs as the basis for the habitat modules, the laboratory modules, and airlocks. The design of those modules has been completed through a critical design review (CDR), and could be constructed for primarily the cost of the hardware, rather than going through a new and expensive design process. Table A-1 lists the elements of each part of the lunar station, the quantity required of each, and the weight. The latter is critical, of course, in transporting the modules and supporting hardware to the Moon. From this table, it can be seen that a total of over 500 tons would need to be lifted to the lunar surface. However, to use the Antarctic analog, this effort need not be accomplished with a few launches. In fact, this paper recommends that the construction of the first lunar base occur over a 22-year period. The pacing of this program will be based on both weight hauled and costs. Since it is likely that costs will be the limiting factor, the launch and construction schedule recommended by this paper will be shown in appendix B, which discusses the funding analog.

Figure A-1 is illustrative of the methodology of using space station modules on the lunar surface. This paper recommends that a space station module be attached to a strongback that contains the retrorocket for landing on the lunar surface. That strongback would also have Apollo lunar rover-type wire wheels and leveling legs. Astronauts on the surface (or remote control from the ground) would guide the lab module into place and then use the leveling legs to situate it in the proper place. The strongback would then become the foundation for the module. It is suggested that the first movement and joining of modules should be handled manually followed by more sophistication over the quarter-century of construction perhaps gradually evolving into construction by remote control.

Figure A-2 shows the simple lunar station regolith mesh holder for solar storms and micrometeoroid protection. This lightweight mesh is wrapped around the module using four posts put into place by astronauts. Shaped charges at the bottom of the posts blasts the necessary hole to hold the posts. Figure A-3 shows an end view of a *Freedom* module in place with the storm fence in place plus a regolith fill around it. To avoid a cave-like interior with no view of the outside, it is suggested that conference rooms and most offices be provided with viewing windows without regolith cover.

Figure A-4 shows the recommended layout of the completed lunar station. The module descriptions are self-explanatory. The components not already designed would include the oxygen plant, the fuel cell module, the solar power grid, and the observatory. All other designs should be able to come off the shelf from space station. Figure A-5 shows the layout of the NSF South Pole Station for comparison. The layout of this lunar station is such that it can be built in stages in the order as shown in appendix B. Essentially, the work will begin with infrastructure (power and utilities, regolith loader, airlocks) and then a laboratory module followed by living quarters. Everything is approached in a gradual build-up, each phase based on what has already come before, paralleling the Antarctic experience.

Table A-1. Lunar base construction requirements.
(Note: Estimated weights based on current S.S. *Freedom* designs)

Element	Quantity	Weight (kg)	Total Weight (kg)
Hab Module/Storm Shelter	1	19,000	19,000
Lab Module	3	22,000	66,000
Airlocks	10	4,000	40,000
Main Entrance	1	9,000	9,000
Greenhouses	2	18,000	36,000
Solar Power Grid	1	20,000	20,000
Vehicle Hangar	1	4,000	4,000
Airbanks	1	20,000	20,000
Pressurized Passageways	6	2,000	6,000
Substation	1	8,000	8,000
Dining/Bar Facility	1	19,000	19,000
Biomed Facility	1	22,000	22,000
Bathroom/Shower Module	1	19,000	19,000
Utility Rooms	2	8,000	16,000
Exercise Facility	1	7,000	7,000
Fuel Cell Module	1	10,000	10,000
Maintenance Facility	1	19,000	19,000
Observatory	1	22,000	22,000
Conference Room/Office	1	19,000	19,000
Suit Room	1	16,000	16,000
Secondary Suit Room	1	8,000	8,000
Library	1	7,000	7,000
Miscellaneous Cables, Ducts, Airlines	1	30,000	30,000
Front-End Loader(s)	2	2,000	4,000
TOTAL			**446,000**

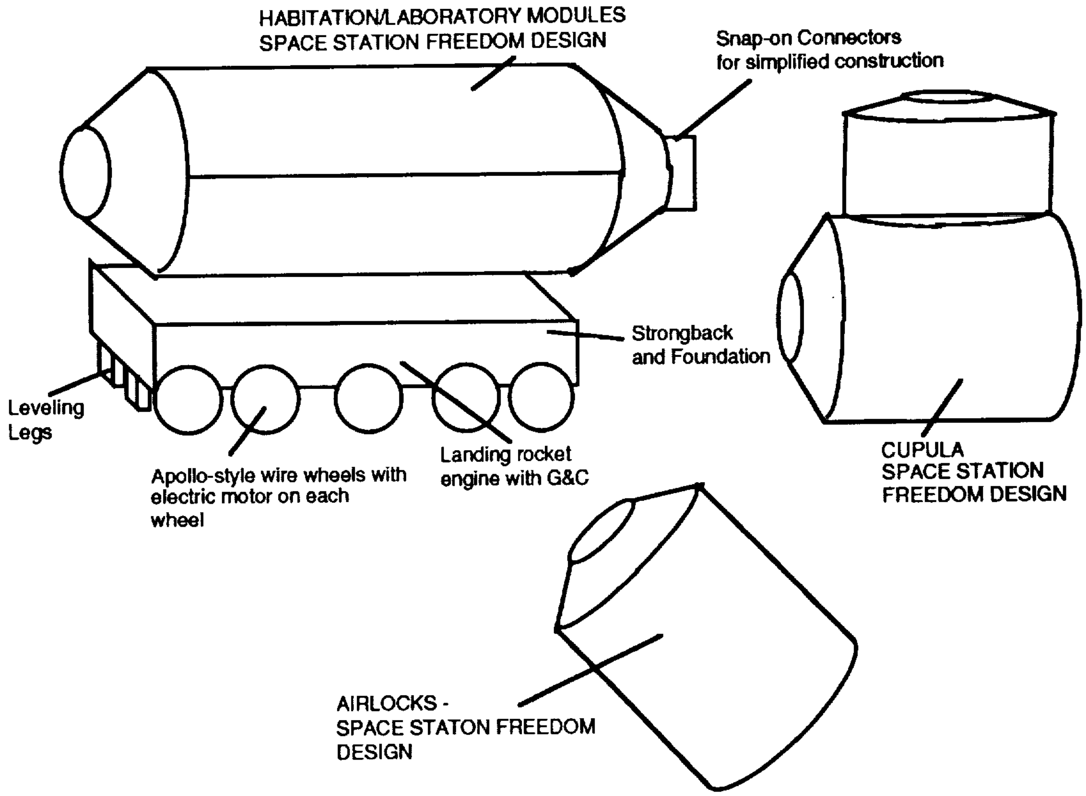

Figure A-1. S.S. *Freedom* modules and landing strongbacks for the lunar base.

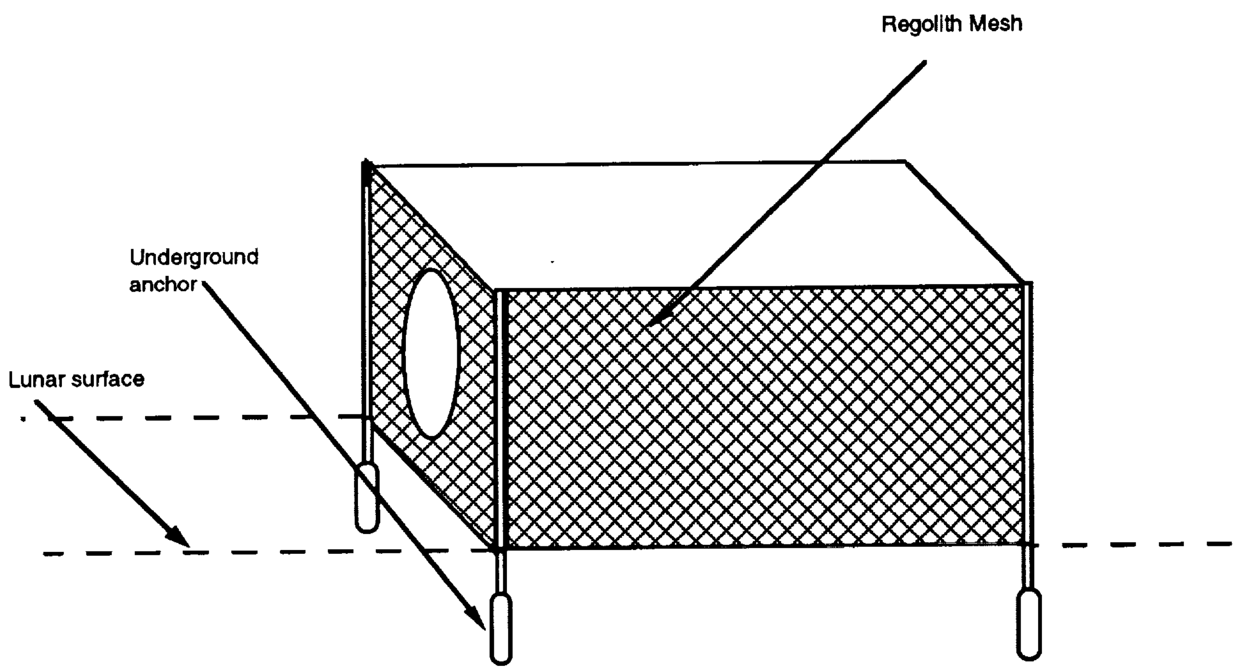

Figure A-2. Simple lunar station regolith mesh holder for module solar storm and micrometeoroid protection.

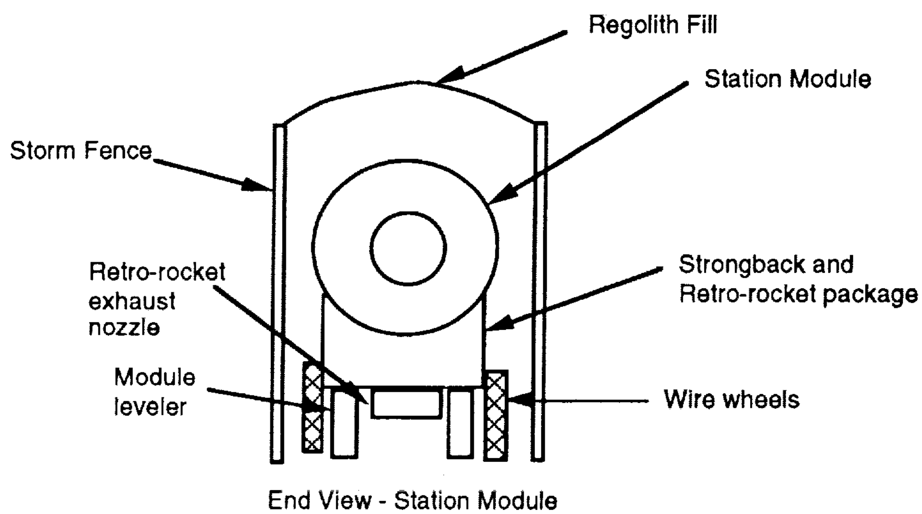

Figure A-3. Solar storm and meteoroid protective cover the NASA/NSF lunar base.

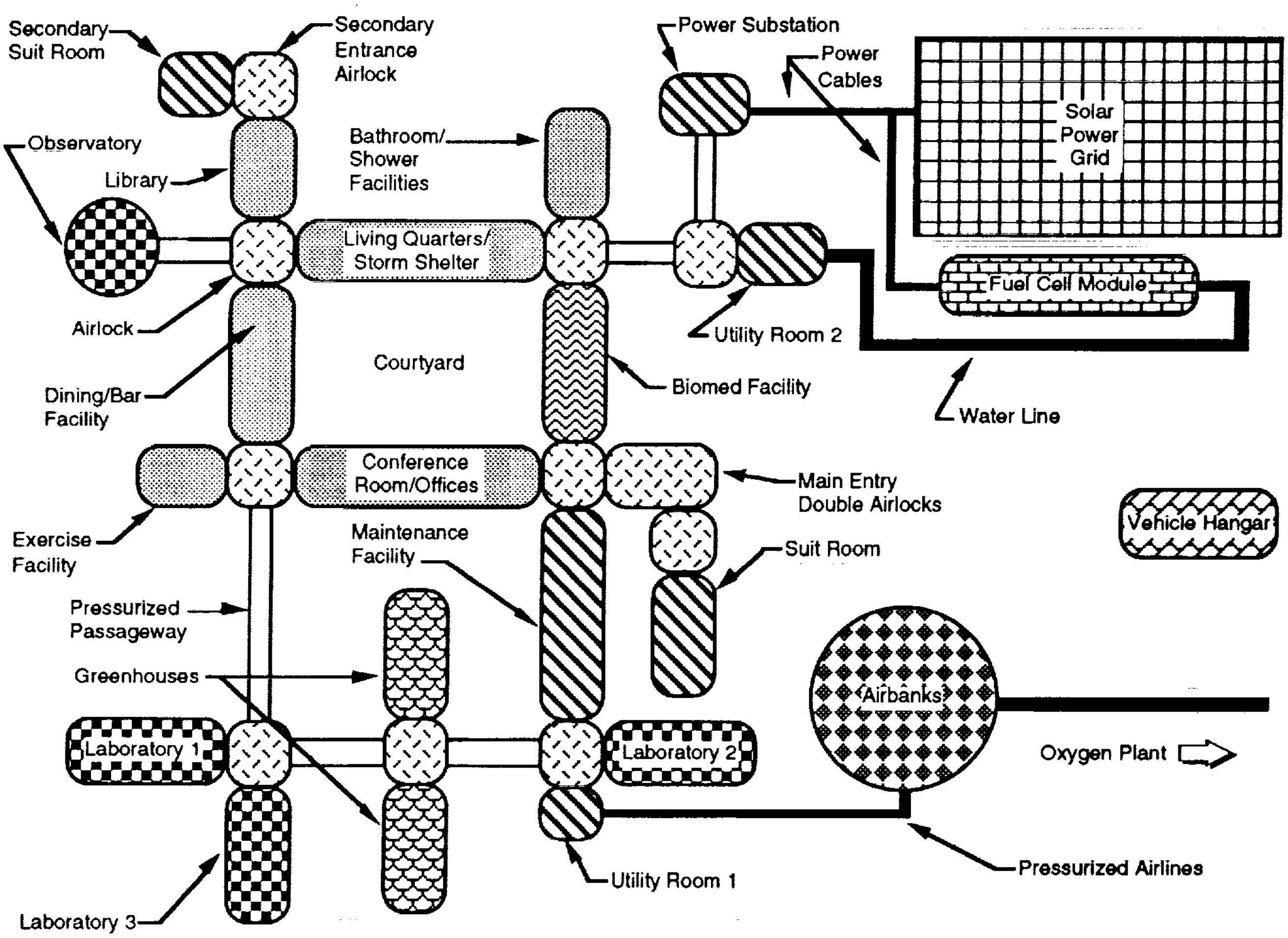

Figure A-4. Lunar station inspired by the NSF South Pole analog.

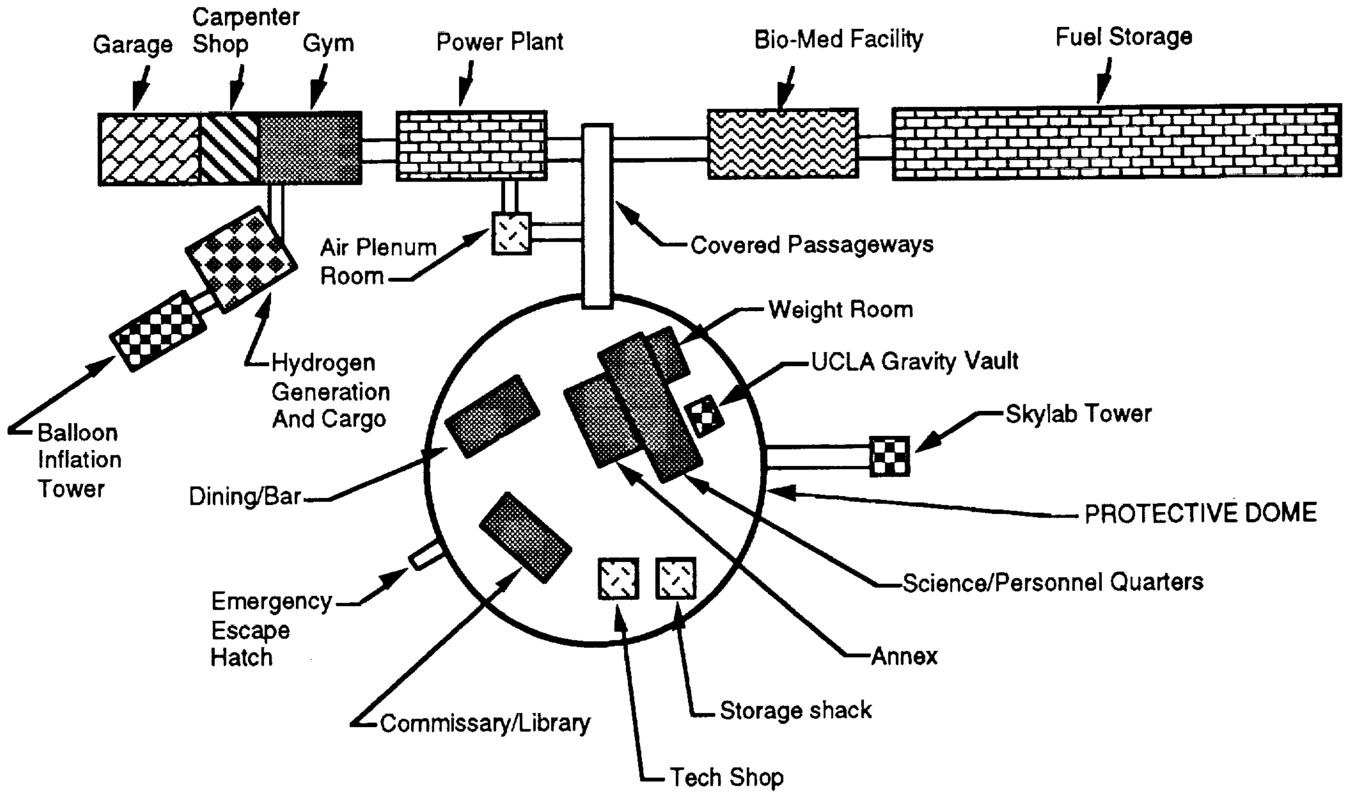

Figure A-5. The NSF South Pole Station.

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APPENDIX B

THE FUNDING ANALOG

The approach by NASA to funding a "new start" program throughout the post-Apollo years is to campaign within the agency for a program and then, after convincing the NASA administrator of the worth of the mission, to attempt to fund it through Congress. The funding effort with Congress can be very simple—listing it in a request for fiscal year funding and letting it stay or be cut without much comment—or it can be a complex, nearly military campaign where space supporters are energized to lobby for the program with both the President and the Congress. This approach causes battle lines to be drawn with friends and foes battling year after year over the project.

For the lunar base, it is suggested that an alternative to that approach be made. First, the program should be designed to work within the American method of funding, the annual fiscal year. No more than $3 billion should be spent annually in constant dollars based on the first fiscal year the program begins. This incremental and steady approach should allow it to become less and less controversial over the 22-year construction period.

Next, only $1.5 billion of this funding per year should come from the Federal Government. The remainder should come from a wide consortium of industrial and scientific organizations and if such funding cannot be gained, then nothing should be accomplished that year. The prospecting for minerals (titanium, etc.) and energy resources (helium-3) should interest companies in those arenas. Universities, pharmaceutical companies, and a variety of research companies should be interested in the lab facilities on the Moon. Of course, the development of Moon-based observatories should excite the interest of many scientific organizations. The entertainment industry should also not be neglected. The lunar base could certainly receive tourists at a later stage in its development and, before that, special guests, including film crews for advertising, and even feature films. Special celebrations could also be held on the Moon. Managers of the lunar base should be aggressive in gaining the necessary funding. In fact, their jobs will depend on it.

The program's life should not be managed by NASA alone, but by a consortium of governmental and industrial partners. International governments may be welcome within the consortium, but it is suggested that it would be less expensive, and with more certain return of the funds spent, to make the consortium as national as possible. This follows the Antarctic experience. International cooperation is certainly a goal, but to date it has not proved to be a very cost-effective way to manage a program. The simplification that comes with a more national approach where the goals are clear is worth more than any international funding and the complex web that then occurs as several governments enter into tangled agreements.

The consortium, which might be called the Lunar Base Consortium (LBC) should have the clear goal of ultimately becoming a profit-making organization and could, within time, be allowed to become a legal United States corporation with all the rights and responsibilities of such. Although this has not been the Antarctic experience, the availability of minerals and energy resources from the lunar surface certainly indicates that the development of the Moon can depart in this one area from the Antarctic analog.

Table B-1 lists the facility and equipment costs and the quantities required for the completed base. Table B-2 illustrates a suggested cost outlay over the 22 years of build-up. This table also

Table B-1. Lunar base modular cost requirements.
(Note: Estimated costs based on space station and known launch designs.)

Element	Quantity	Unit Cost ($M)	Total Cost ($M)
Hab Module	1	40	40
Lab Module	3	70	210
Airlocks	10	14	140
Main Entrance	1	10	10
Greenhouses	2	10	20
Solar Power Grid	1	200	200
Vehicle Hangar	1	10	10
Airbanks	1	40	40
Pressurized Passageways	6	6	36
Substation	1	24	24
Dining/Bar Facility	1	44	44
Library	1	16	16
Biomed Facility	1	80	80
Bathroom/Shower Module	1	20	20
Utility Rooms	2	30	60
Exercise Facility	1	16	16
Fuel Cell Module	1	200	200
Maintenance Facility 1	80	80	80
Observatory	1	500	500
Conference Room/Office	1	36	36
Suit Room	1	50	50
Secondary Suit Room	1	40	40
Miscellaneous Cables, Ducts, Airlines	1	200	200
Front-end Loaders	2	25	50
MODULAR SUB-TOTAL			**$2,122**
Strongbacks/Landers (Heavy)	13	500	6,500
Strongbacks/Landers (Medium)	8	400	3,200
Strongbacks/Landers (Light)	14	350	4,900
LANDER SUB-TOTAL			**$14,600**
TOTAL			**$16,722**

lists the elements that would be launched to the lunar surface during each fiscal year. These set of launches are referred to as "modules." It is recommended that each module be managed by a module manager, with all responsibility to see that the module is constructed and launched within the budget. It should be a particular goal of the LBC to get more and more efficient in terms of administration and overhead. Module managers would be encouraged in this since the more administration and overhead, the less he or she has to spend on construction and launching. Efficiencies should, therefore, occur as a matter of course. Note that table B-2 also lists the launcher recommended to be used. This is further explained in appendix C, the transportation analog. Table B-3 accounts for the total cost of the program over the 22-year period.

Table B-2. Lunar base pacing.

Note: It will be a goal of the program to spend no more than 3 billion FY93 constant dollars per year during the 22-year build-up of the lunar station. The exception to this are the three manned launches during that period. These will be costed at $6 billion each. It is expected, however, that this cost may be decreased as the program goes on due to efficiencies that may occur during an operational program. One billion dollars (or slightly less to compensate for a heavy launch year) for administration, overhead, and other services will be assumed per year.

Module 1 - FY01		
ELEMENT	LAUNCHER	COSTS ($M)
Solar Grid	Moondog	1,500
Power Substation	Mooncat	774

Module 2 - FY02		
ELEMENT	LAUNCHER	COSTS ($M)
Misc. Equipment	Moonbird	610
Utility Room 2 + Water	Mooncat	730
Airlock + Air	Moonbird	614

Module 3 - FY03		
ELEMENT	LAUNCHER	COSTS ($M)
Passageway/Loader	Moonbird	631
Airlock + Air	Moonbird	614
Passageway/Loader	Moonbird	606
Airlock + Air	Moonbird	631

Module 4 - FY04		
ELEMENT	LAUNCHER	COSTS ($M)
Bathroom/Shower	Moondog	1,320
Main Entry	Mooncat	759

Module 5 - FY05		
ELEMENT	LAUNCHER	COSTS ($M)
Biomed Facility	Moondog	1,380
Airlock + MRE	Moonbird	614

Table B-2. Lunar base pacing (continued).

Module 6 - FY06		
ELEMENT	LAUNCHER	COSTS ($M)
Living Quarters	Moondog	1,340
Storm Mesh + Misc. Equipment	Moonbird	610

ELEMENT	LAUNCHER	COSTS ($M)
MANNED MISSION #1	***Moondog***	***6,000***

Module 7 - FY07		
ELEMENT	LAUNCHER	COSTS (M)
Airlock + MRE	Moonbird	614
Suit Room	Moondog	1,350

Module 8 - FY08		
ELEMENT	LAUNCHER	COSTS ($M)
Maintenance Facility	Moondog	1,380
Miscellaneous Equipment	Moonbird	610

Module 9 - FY09		
ELEMENT	LAUNCHER	COSTS ($M)
Laboratory 2	Moondog	1,370
Utility Room 1 + Water	Mooncat	730

Module 10 - FY10		
ELEMENT	LAUNCHER	COSTS ($M)
Conference Room/Offices	Moondog	1,336
Airlock + Air	Moonbird	614

Module 11 - FY11		
ELEMENT	LAUNCHER	COSTS ($M)
Airlock	Moonbird	614
Dining/Bar Facility	Moondog	1,344

Table B-2. Lunar base pacing (continued).

Module 12 - FY12		
ELEMENT	LAUNCHER	COSTS ($M)
Passageway + Water	Moonbird	606
Passageway + Water	Moonbird	606
Passageway + Water	Moonbird	606

ELEMENT	LAUNCHER	COSTS ($M)
MANNED MISSION #2	***Moondog***	***6,000***

Module 13 - FY13		
ELEMENT	LAUNCHER	COSTS ($M)
Observatory	Moondog	1,800

Module 14 - FY14		
ELEMENT	LAUNCHER	COSTS ($M)
Library	Moondog	1,320
Secondary Entrance	Moonbird	614

Module 15 - FY15		
ELEMENT	LAUNCHER	COSTS ($M)
Secondary Suit Room	Mooncat	790
Exercise Facility	Mooncat	766
Miscellaneous Equipment	Moonbird	610

Module 16 - FY16		
ELEMENT	LAUNCHER	COSTS ($M)
Airlock	Moonbird	614
Lab 1	Moondog	1,370

Module 17 - FY17		
ELEMENT	LAUNCHER	COSTS ($M)
Lab 3	Moondog	1,370
Airlock	Moonbird	614

Table B-2. Lunar base pacing (continued).

Module 18 - FY18		
ELEMENT	LAUNCHER	COSTS ($M)
Passageway	Moonbird	606
Greenhouse	Moondog	1,310

Module 19 - FY19		
ELEMENT	LAUNCHER	COSTS ($M)
Fuel Cell Module	Moondog	1,500
Miscellaneous Equip.	Moonbird	610

ELEMENT	LAUNCHER	COSTS ($M)
MANNED MISSION #3	***Moondog***	***6,000***

Module 20 - FY20		
ELEMENT	LAUNCHER	COSTS ($M)
Oxygen Plant	Moondog	3,000

Module 21 - FY21		
ELEMENT	LAUNCHER	COSTS ($M)
Airbanks	Moondog	1,320
Miscellaneous Equipment	Moonbird	610

Module 22 - FY22		
ELEMENT	LAUNCHER	COSTS ($M)
Extra Solar Power Grid	Moondog	1,500
Miscellaneous Equipment	Moonbird	610

ELEMENT	LAUNCHER	COSTS ($M)
MANNED MISSION #4	***Moonbeast***	***6,000***

ELEMENT	LAUNCHER	COSTS ($M)
Steady State – FY23	Moonbeast	3,000
Steady State – FY24	Moonbeast	3,000
Steady State – FY25	Moonbeast	3,000

And so forth...

Table B-3. Total cost of program.

TYPE COST	TOTAL COST ($M)
Launch Services	1,000
Launch Vehicles	17,500
Modules/Strongbacks	16,722
Administration/Overhead	10,000
Contingencies/Inflation	10,000
Other	20,000
TOTALS	**$75,222**

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APPENDIX C

THE TRANSPORTATION ANALOG

The United States South Pole Station is serviced through the use of United States Navy and Air Force aircraft, with some slight supplement by other Government and private aircraft. The Navy and Air Force are then reimbursed by the NSF for this service. It is suggested that the rather massive movement of modules, infrastructure, and expendables to the lunar base be handled in the same way—essentially a subcontract to a separate entity for the transportation—an entity which has experience in space transportation. This entity can be either NASA, the Air Force, or a consortium of aerospace contractors. It should, in any case, be one of the above and not a mixture of all three. It should be the goal of this program to reduce overhead and administrative costs. Having a wide consortium of agencies and nongovernmental institutions trying to operate any project has always been inefficient. The LTU should subcontract to the most efficient agency or consortium and stick with it as long as it is a mutually beneficial relationship.

As of now, the principle aircraft used to support the South Pole Station is the C-130 aircraft, a turboprop cargo carrier which has been in service since the early 1960's. It is an efficient carrier for which there is a wide understanding of maintenance and service procedures, plus an inventory of repair and replacement parts. The C-130 exists, however, for many other uses other than resupply and construction of the South Pole Station. That is why it is a cost-effective aircraft to use. It is similarly suggested that the lunar base use space boosters already in the inventory for construction and resupply. This is an important point. No funds should be expended to build a new booster. It simply would drive up the costs of the program. It is suggested, however, that over the 22-year period of the program, eventually new technology will create a more efficient heavy-lift booster that will be available to the lunar base. This would probably not happen until the latter phases of lunar base construction.

The launch vehicles to be used for the construction and resupply of the lunar base is shown in table C-1. For simplification, they are referred to as a stable of easily recognizable names: Moondog (the shuttle plus Titan IV and Centaur), Mooncat (Titan IV and Centaur), and Moonbird (Atlas and Centaur).

Table C-2 lists the number of launcher types that will be required over the entire quarter-century of construction of the lunar base. It is also recommended, as shown in this table, that the route to the Moon for the transportation of the various unmanned modules of the lunar base be the "fuzzy boundary" route to the Moon rather than the classic Hohmann transfer route. The fuzzy boundary route, shown in figure C-1, was first outlined by mathematicians Edward Belbruno and Jaume Llibre (please see bibliography) as a breakthrough calculation of orbits and trajectories that greatly reduces the amount of fuel needed to get to the other planets. The fuzzy boundary is the region where the effects of both Sun and Earth gravity are nearly the same. A spacecraft that flies to this boundary (usually using the Moon for a gravity assist on the way) can be nudged back to the Moon and into orbit without the expenditure of propellant required for braking. This means a large savings in the weight of the spacecraft. The only drawback to the fuzzy boundary route is that it requires more time to get to the Moon than the classic route. The Hohmann transfer requires only about 3 days to get to the Moon. The fuzzy boundary route will require several weeks or even months. For the construction of the lunar base, however, the lag in time to the Moon should be no problem for the unmanned modules.

Table C-3 lists the strongback/landers required to place the various construction components on the lunar surface including a suggested cost for each. These strongback/landers would require a "new start" design and construction but could borrow heavily from the Apollo lunar module and lunar rover experience.

Figures C-2 and C-3 are illustrative of the various launcher combinations recommended and the number of launches required for each over the quarter-century of lunar base construction. Figure C-4 illustrates the "Moonbeast" heavy launcher that might be designed and built for many purposes besides the lunar base during the first part of the 21st century. The Moonbeast would be a very efficient booster and would be designed to be cost effective. The LTU would, of course, seek to use it.

Table C-1. Launcher combinations.

(Note: Launch costs and payload weights based on estimates as presented in *Launch Options of the Future*, 1988, Congress of the United States and other resources)

Launch Vehicle(s)	Payload to Moon (kg)	Cost of Launch ($M)
Moondog – (STS rendezvous with Titan IV/Centaur)	22,000	800
Mooncat – (Titan IV/Centaur)	10,000	350
Moonbird – (Atlas/Centaur)	5,000	250

Table C-2. Launcher requirements for complete lunar base.

Launch Vehicle(s)	Payload	Quantity Required
Moondog	Heavy	14
Mooncat	Medium	8
Moonbird	Light	14

Table C-3. Lunar base strongback/lander requirements.

Element	Type Lander	Quantity Required	Cost ($M)
Hab/Lab	Heavy (10-20,000 kg)	14	11,200
Specialty	Medium(5-10,000 kg)	8	2,800
Airlocks, etc.	Low (< 5,000 kg)	14	3,500
Total Launches		**35**	**$17,500**

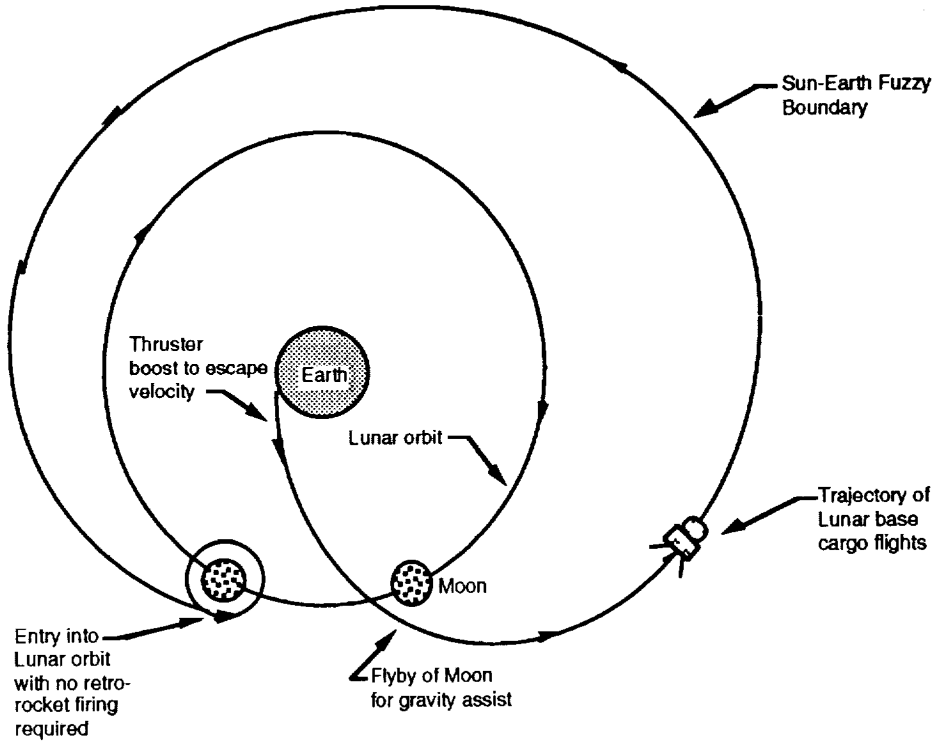

Figure C-1. Fuzzy boundary route to the Moon.

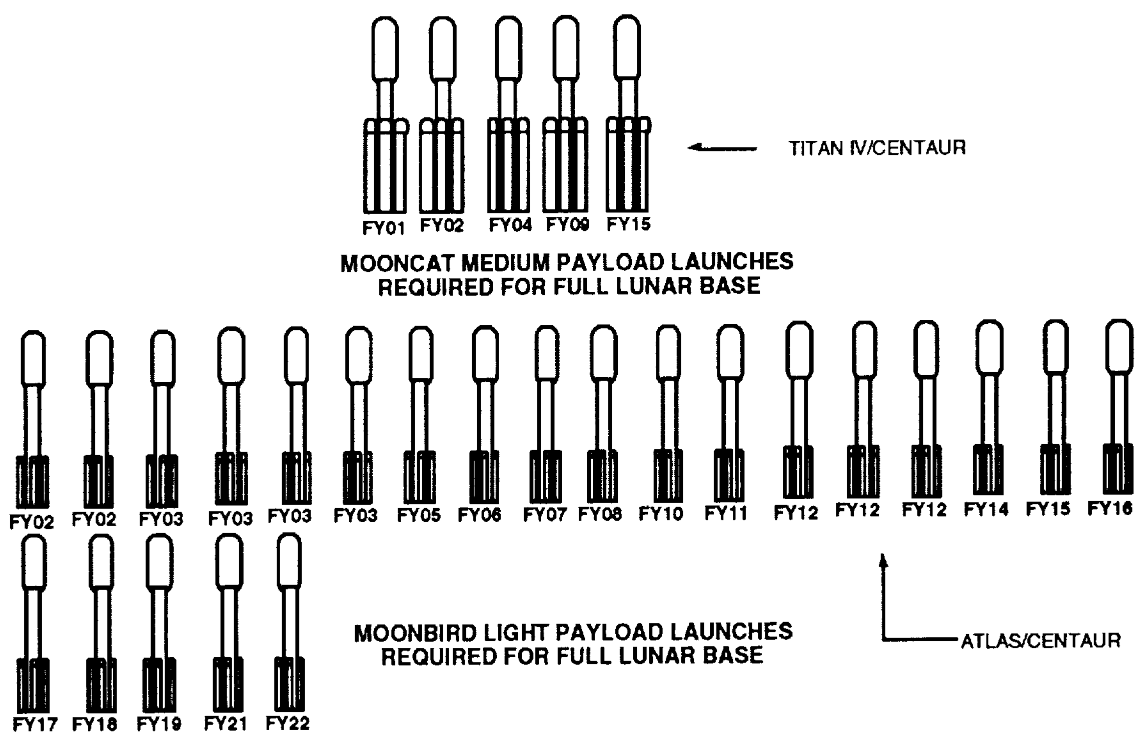

Figure C-2. Medium and light launchers required for lunar base.

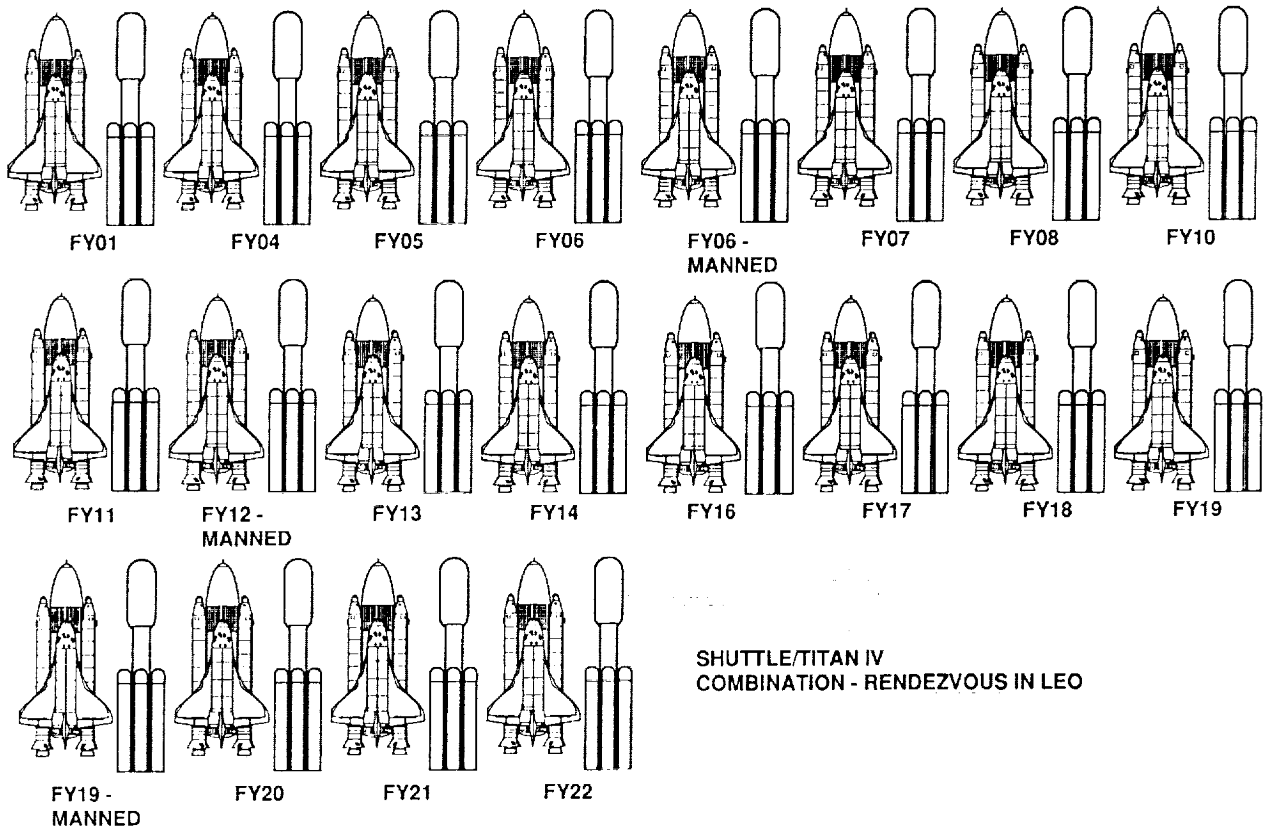

Figure C-3. Heavy launchers required for full lunar base.

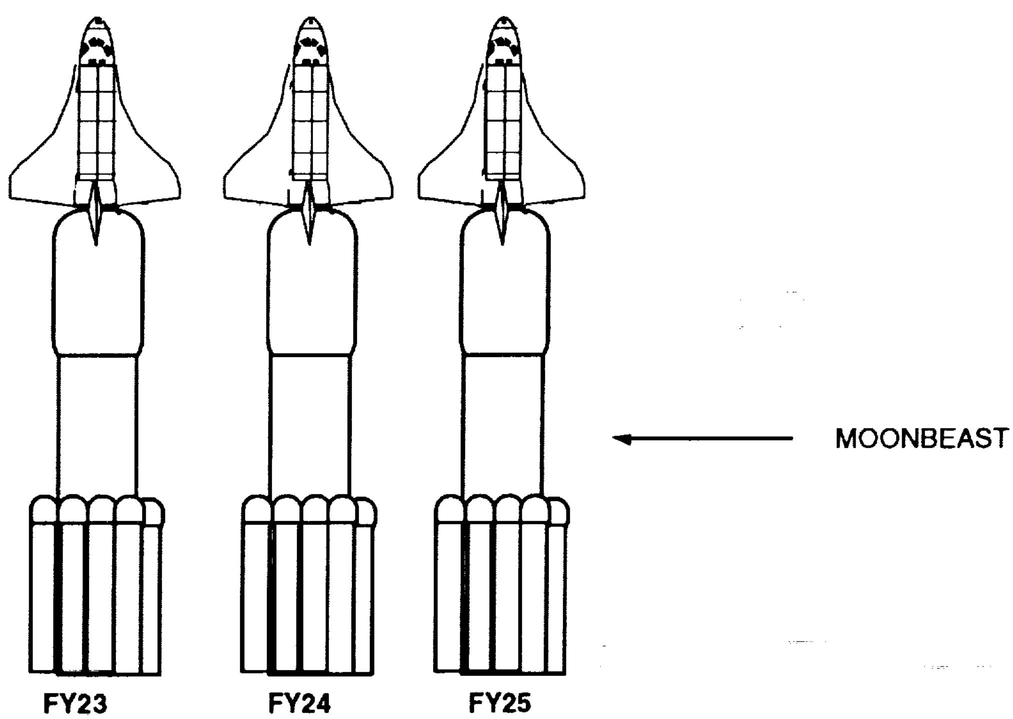

Figure C-4. Extra-heavy launchers needed for steady-state operation of lunar base.

APPENDIX D

ANNUAL EXPENDABLES REQUIREMENT FOR A LUNAR BASE AND A 6-PERSON STAFF (based on United States Army Field Manual 5-34)

Requirement	*Per Person Per Day*	*Annual Req.*	*Weight (lb)*
Potable Water	5 gallons	10,950 gal.	91,376
Non-potable Water	4 gallons	8,760 gal.	73,058
Food	4 MRE *	8,760 MRE	17,250
Air	2.3 lbs.	4,035 lbs.	4,035

* Meals Ready to Eat

Initial Cargo:

Water = 13,702 lb (enough for one month, unrecycled)
Air = 336 lb (enough for one month, unrecycled)

Assumed Loss Rates:

Water = 20 percent annually
Air = 50 percent annually

Annual Cargo Requirements:

Water = 2,740 lb
Food = 17,250 lb
Air = 168 lb

Total = 20,428 lb or 9,285 kg.

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APPENDIX E

QUESTIONNAIRE FOR THE NATIONAL SCIENCE FOUNDATION

Questionnaire Relating to the National Science Foundation South Pole Station

FACILITIES:

1. Provide a general layout of the South Pole Station.
2. Provide interior layouts of each facility, use of each area, and square feet available in each area.
3. How were the interior layouts determined?
4. How as the general architecture of the station determined and designed?
5. What materials were used in the construction of each facility?
6. What were the design specificiations of the facility? Strengh of materials, insulation, etc.?
7. How long did it take to construct each facility? How many workers used? What equipment was used?

Questionnaire
Relating to the National Science Foundation
South Pole Station

ENERGY:

1. How is electrical power provided to the station? What is the cost of the power plant(s), how much does it weigh, is there any special handling required, special construction, materials?

2. What is the generated capacity of the main power plant? Auxiliary and back-up plants?

3. How much electric cabling is required? What size? What weight? Is it strung overhead or underground? How was that done?

4. What is the recorded energy demand of the station? Does it very by season? Can the energy demand be broken out by area of use?

5. What kind of electricity is provided? AC or DC? 110 or 220? 60 cycles? Etc.?

6. Are there other forms of energy provided? Gas heat?

Questionnaire
Relating to the National Science Foundation
South Pole Station

COMMUNICATIONS:

1. How are communications to the outside provided at the station? Are there backups?

2. What kind of communications are required?

3. How much traffic is logged?

4. How often are crew members allowed to communicate with friends and family? Are communications private?

Questionnaire
Relating to the National Science Foundation
South Pole Station

MAINTENANCE:

1. How are facilities maintained? Is there a schedule for this maintenance? Who does it and how often?

2. How are the power plants maintained? Is there a schedule for this maintenance? Who does it and how often?

3. Does each crew person clean their own space or are housekeeping duties rotated in some way?

4. Is there a log of necessary repairs on the facility and power plants over and above routine mainenance?

Questionnaire
Relating to the National Science Foundation
South Pole Station

FOOD:

1. What quantity of food is required to support the station during the average month?

2. What kind and quantity of each kind of food is required during the average month?

3. How is the type of food determined?

4. What support equipment is required for food handling and preparation? Refrigerators? Stoves? Utensils? Dinnerware?

5. How is waste food disposed?

6. How much food spoils during the average month?

7. Who does the food preparation?

8. How are meals handled—family style, cafeteria style, pre-packaged, self-prepared?

Questionnaire
Relating to the National Science Foundation
South Pole Station

WATER:

1. How much water is required per person per week in the station?

2. How is the water used?

3. Breakout of water use (per person)?

   a. Personal hygiene
   b. Cooking
   c. Laundry
   d. Sewage
   e. Drinking
   f. Facility/Equipment cleaning
   g. Other

4. How is the water obtained? Is any of it recycled? How is it recycled?

Questionnaire
Relating to the National Science Foundation
South Pole Station

HEALTH AND HYGIENE:

1. How is the health of the crew supported? What kind of medical staff?
2. Are the crews given special medical training?
3. What medical supplies are kept on hand? How long is this amount intended to support how many personnel?
4. What medical care facilities are provided?
5. What medical equipment?
6. Is there a problem with fungal infections?
7. What medical emergencies have occurred during "wintering over" periods?
8. Do the crews participate in an exercise program? What kind of exercise equipment?
9. Is odor control required? What kind of odors accumulate?
10. What special hygiene efforts are required?
11. Is sound control a problem? Are there "good" or "bad" sounds?
12. What hygiene is required? How is this supervised?
13. How often do crews change clothes? Any facilities for washing clothes?
14. Is alcohol permitted during "wintering over" periods?
15. What is the policy regarding the use of medicinal drugs?
16. Are there psychological problems? What kind? Any recurring ones? How are these handled?
17. Do long periods of isolation cause problems between crew members?
18. Is any psychological/personality screening done prior to assignment? Is there any further psychological support given to the crews?

Questionnaire
Relating to the National Science Foundation
South Pole Station

TRAINING:

1. How are crews selected and trained?

2. Are there any areas that require special training?

3. Are crews given any training in group communications and teamwork before wintering over?

Questionnaire
Relating to the National Science Foundation
South Pole Station

SCHEDULES:

1. What are the work schedules and supervision required? Do crews work in shifts? On their own? Other plans?

2. What other schedules are maintained? Who determines them?

Questionnaire
Relating to the National Science Foundation
South Pole Station

RECREATION:

1. What recreation is provided the crews?

2. What recreation seems the best?

3. How much recreation seems to be best?

4. Do all crew members seem to need the same amount of recreation?

Questionnaire
Relating to the National Science Foundation
South Pole Station

CREW CONSIDERATIONS:

1. How is personal time handled? Scheduled?

2. What is the cultural/gender mix of crews? Any problems?

3. Is there any adjustment period for crews after they arrive?

4. Is there any re-adjustment time needed when crews go home?

Questionnaire
Relating to the National Science Foundation
South Pole Station

WORK/SCIENCE PERFORMED:

1. What generic science equipment and supplies are at the station? How were these determined? Weight and quantity of this equipment?

2. To what extent do the expedition members control the experiments? Are they more like mission specialists or more like principal investigators?

Questionnaire
Relating to the National Science Foundation
South Pole Station

OUTSIDE OPERATIONS:

1. How often do the crews go out on the ice? Why do they go out?

2. What kind of outside transportation is provided?

3. How far do they go from the base? What is the procedure if a crewman is lost?

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APPENDIX F

NSF SOUTH POLE STATION INFORMATION AVAILABLE FROM THE NATIONAL ARCHIVES, WASHINGTON DC

Central file: RG307 National Science Foundation
Office of Antarctic Programs
(OAP) Central Subject K.6S
South Pole Station

Number	Boxes	Title
105.10	77	South Pole Station (Gen.) incl. plans for facilities
105.10a	77	South Pole St. replacement facility '65–'69
105.13	80	Pole Station (1959-64)
105.13.1		Replacement of Pole Station (Bureau of Yards and Docks)
105.13.2		Pole Station Inventory, 1958-62
105.13.5		Pole Station Photos and Sketches

Contact: Marjorie Ciarlante
Civil Reference Branch
National Archives
Phone: 202–501–5395

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APPROVAL

STUDY OF THE NATIONAL SCIENCE FOUNDATION'S SOUTH POLE STATION AS AN ANALOGOUS DATA BASE FOR THE LOGISTICAL SUPPORT OF A MOON LABORATORY
(Center Director's Discretionary Fund Final Report No. 307-51-00-N09)

By H.H. Hickam, Jr.

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nucler energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

C.S. GRINER
Director, Mission Operations Laboratory

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